

# Fermi observations of TeV AGN

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We report on observations of TeV-selected AGN made during the first 5.5 months of observations with the Large Area Telescope (LAT) on-board the *Fermi* Gamma-ray Space Telescope (*Fermi*). In total, 28 TeV AGN were selected for study. The *Fermi* observations show clear detections of 21 of these TeV-selected objects. Most can be described with a power law of spectral index harder than 2, with a spectral break generally required to accommodate the TeV measurements. Evidence for systematic evolution of the gamma-ray spectrum with redshift is presented and discussed in the context of the EBL.

## 1. Introduction

At energies above approximately 100 GeV (the TeV energy regime), ground-based gamma-ray observatories have detected 96 sources over the past two decades. The pace of discovery in this energy regime has been particularly high since the inception of the latest generation of instruments: H.E.S.S., CANGAROO, MAGIC and VERITAS. The majority of the TeV sources are galactic, however 30 extragalactic sources have also been detected, of which 28 correspond to Active Galactic Nuclei (AGN), the other two being starburst galaxies. Most (25) of these TeV AGN are blazars.

The Large Area Telescope is a pair-conversion telescope on the *Fermi* Gamma-ray Space Telescope (formerly GLAST), launched in June 2008. The *Fermi*-LAT instrument detects gamma rays with energies between 20 MeV and  $>300$  GeV (the GeV energy regime). In this poster we present the results of *Fermi*-LAT observations of the known TeV blazars. The motivation for this study is two-fold: (i) to present as complete a picture of the high-energy emission as possible by combining the GeV and TeV results on these objects, and (ii) to help guide future TeV observations. For a selection of these GeV–TeV objects we present the GeV spectrum from *Fermi* and extrapolate it to TeV energies assuming absorption on the EBL, and compare these extrapolations to archival TeV measurements. Finally, we study the evolution of the spectrum of these objects as a function of redshift.

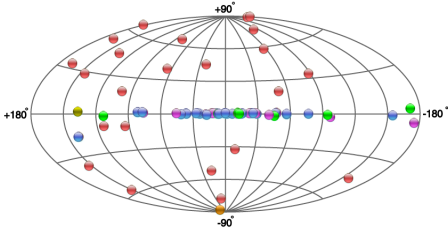


Figure 1: TeV sources, from TeVCat (<http://tevcatalog.uchicago.edu/>).

## 2. Results summary – Detected GeV–TeV AGN

Table I presents the results of 5.5 months of observation of the TeV AGN with the *Fermi* LAT [for detailed discussion of analysis and results and a comprehensive list of references to TeV data see 1]. Of the 28 objects selected for observation, a total of 21 were detected with  $TS > 25$  (approximately  $5\sigma$ ). This degree of connection between the TeV blazars and the GeV regime was not found by EGRET and the previous generation of TeV instruments, and is evident now only as a result of the improved sensitivity and greater overlap between the effective energy ranges of *Fermi* and the current generation of TeV instruments.

The majority of the TeV blazars detected by *Fermi* have a photon index  $\Gamma \leq 2$  in the GeV regime, the median index is  $\Gamma = 1.9$ . In contrast, the populations of 42 BL Lacs and 57 FSRQs from the LBAS sample have median indexes of  $\Gamma = 2.0$  and  $\Gamma = 2.4$  respectively. The TeV blazars are amongst the hardest extragalactic objects detected by *Fermi*. For many of the sources, especially those with harder spectra, no evidence for curvature is seen in the LAT energy range. Furthermore, many sources did not show evidence of significant variability over the period of the study.

## 3. Discussion of selected AGN

**3C 66A/B:** TeV emission from this region detected by VERITAS (3C 66A, HBL,  $z = 0.444$ ) and MAGIC (3C 66B, RG,  $z = 0.0211$ ). *Fermi* detects hard GeV emission, coincident with 3C 66A (Figures 2 and 3). An extrapolation of the GeV spectrum to TeV energies is in better agreement with the TeV data measurements assuming  $z = 0.444$  than  $z = 0.0221$ .

**PKS 2005-489:** A H.E.S.S.-detected HBL with no evidence of TeV variability. *Fermi* detects hard steady emission from this source (Figure 4). An extrapolation of the GeV spectrum to TeV energies over-

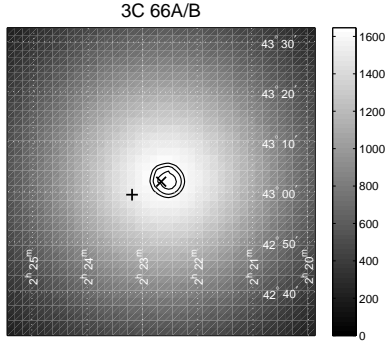


Figure 2: TS map of the 3C 66A/B region.

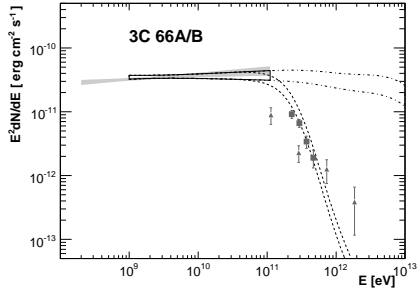


Figure 3: Spectrum for 3C 66A/B region.

predicts the TeV spectrum, suggesting the presence of intrinsic curvature in the spectrum of PKS 2005-489.

**3C 279:** Detected by MAGIC during a flaring episode, 3C 279 is the most distant TeV source (with a known redshift) detected to date. The *Fermi* spectrum is relatively soft, and shows clear evidence for curvature (Figure 5). During the period of the study the flux from 3C 279 increased by a factor of  $\sim 5$  in a flare that lasted  $\sim 50$  days. The spectra for the flaring and non-flaring emission is shown. An extrapolation of both to TeV energies under-predicts the flux measured by MAGIC, showing that it must correspond to a extreme flaring state.

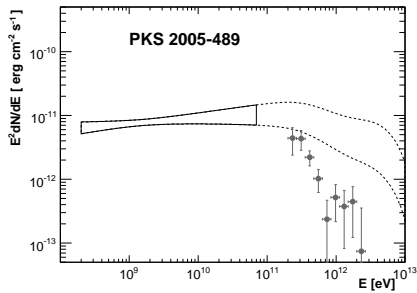


Figure 4: Spectrum for PKS 2005-489.

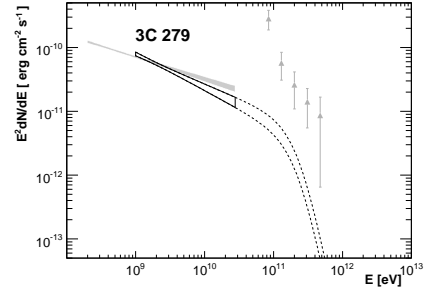


Figure 5: Spectrum for 3C 279.

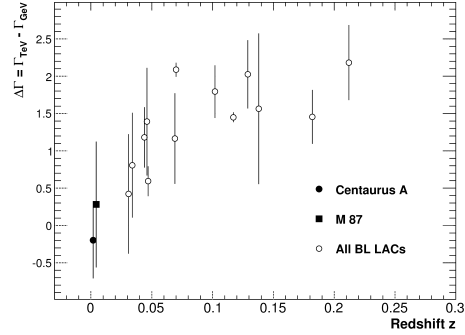


Figure 6: Difference in TeV and GeV spectral indices for GeV-TeV AGN.

#### 4. Evolution of spectra with redshift

In the LBAS study [2], no significant relation between the GeV photon index and redshift was found for either the sample of BL Lacs or FSRQs. The GeV-TeV sources provide a population in which the effects of spectral evolution with redshift can be studied across a much wider energy range than LBAS. The presence of a redshift-dependent spectral break in these sources could be indicative of the effects of absorption on the EBL, and provide experimental evidence for this absorption in a manner independent of any specific EBL-density model. The difference in the TeV and GeV spectral indices for 15 of the GeV-TeV sources is shown in Figure 6. It is evident that the difference between the GeV and TeV spectral indices increases with redshift. At low redshifts the radio galaxies M 87 and Cen A have  $\Delta\Gamma \sim 0$ , as do the near-by BL Lacs. At  $z > 0.1$ , all of the BL Lacs are consistent with  $\Delta\Gamma \geq 1.5$ .

#### 5. Conclusions

In 5.5 months of observation the *Fermi* LAT has detected GeV emission from 21 TeV-selected AGN (and from 17 previously observed by TeV groups for which upper limits have been published). Many exhibit an increasing spectrum ( $\Gamma < 2$ ) in the GeV range con-

firming the presence of a high energy peak in  $\nu F_\nu$  representation. The intrinsic spectrum for some of the TeV sources can be well described by a single power-law across the energy range spanned by the *Fermi* LAT and the TeV observatories, with any breaks in the measured gamma-ray spectra between the two regimes being consistent with the effects of absorption with a model of minimal EBL density. Redshift-dependent evolution is detected in the spectra of objects detected at GeV and TeV energies. The most reasonable explanation for this is absorption on the EBL.

## Acknowledgments

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## References

- [1] Abdo, A. A., et al., 2009, ApJ, 707, 1310
- [2] Abdo, A. A., et al., 2009, ApJ, 700, 597

Table I TeV AGN detected by the *Fermi*/LAT in 5.5 months of observation

Name	$\alpha_{J2000}$	$\delta_{J2000}$	Type <sup>a</sup>	$z$	Ref
<b>Blazars:</b>					
RGB J0152+017	01 <sup>h</sup> 52 <sup>m</sup> 39.6 <sup>s</sup>	+01° 47' 17''	HBL	0.080	1
3C 66A	02 <sup>h</sup> 22 <sup>m</sup> 39.6 <sup>s</sup>	+43° 02' 08''	IBL	0.444 <sup>b</sup>	2,3 <sup>c</sup>
1ES 0229+200	02 <sup>h</sup> 32 <sup>m</sup> 48.6 <sup>s</sup>	+20° 17' 17''	HBL	0.140	4
1ES 0347-121	03 <sup>h</sup> 49 <sup>m</sup> 23.2 <sup>s</sup>	−11° 59' 27''	HBL	0.188	5
PKS 0548-322	05 <sup>h</sup> 50 <sup>m</sup> 40.8 <sup>s</sup>	−32° 16' 18''	HBL	0.069	6
RGB J0710+591	07 <sup>h</sup> 10 <sup>m</sup> 30.1 <sup>s</sup>	+59° 08' 20''	HBL	0.125	7
S5 0716+714	07 <sup>h</sup> 21 <sup>m</sup> 53.4 <sup>s</sup>	+71° 20' 36''	LBL	0.300	8
1ES 0806+524	08 <sup>h</sup> 09 <sup>m</sup> 49.2 <sup>s</sup>	+52° 18' 58''	HBL	0.138	9
1ES 1011+496	10 <sup>h</sup> 15 <sup>m</sup> 04.1 <sup>s</sup>	+49° 26' 01''	HBL	0.212	10
1ES 1101-232	11 <sup>h</sup> 03 <sup>m</sup> 37.6 <sup>s</sup>	−23° 29' 30''	HBL	0.186	11
Markarian 421	11 <sup>h</sup> 04 <sup>m</sup> 27.3 <sup>s</sup>	+38° 12' 32''	HBL	0.031	12
Markarian 180	11 <sup>h</sup> 36 <sup>m</sup> 26.4 <sup>s</sup>	+70° 09' 27''	HBL	0.046	13
1ES 1218+304	12 <sup>h</sup> 21 <sup>m</sup> 21.9 <sup>s</sup>	+30° 10' 37''	HBL	0.182	14
W Comae	12 <sup>h</sup> 21 <sup>m</sup> 31.7 <sup>s</sup>	+28° 13' 59''	IBL	0.102	15
3C 279	12 <sup>h</sup> 56 <sup>m</sup> 11.2 <sup>s</sup>	−05° 47' 22''	FSRQ	0.536	16
PKS 1424+240	14 <sup>h</sup> 27 <sup>m</sup> 00.4 <sup>s</sup>	+23° 48' 00''	IBL	...	17
H 1426+428	14 <sup>h</sup> 28 <sup>m</sup> 32.7 <sup>s</sup>	+42° 40' 21''	HBL	0.129	18
PG 1553+113	15 <sup>h</sup> 55 <sup>m</sup> 43.0 <sup>s</sup>	+11° 11' 24''	HBL	0.09 – 0.78	19
Markarian 501	16 <sup>h</sup> 53 <sup>m</sup> 52.2 <sup>s</sup>	+39° 45' 37''	HBL	0.034	20
1ES 1959+650	19 <sup>h</sup> 59 <sup>m</sup> 59.9 <sup>s</sup>	+65° 08' 55''	HBL	0.048	21
PKS 2005-489	20 <sup>h</sup> 09 <sup>m</sup> 25.4 <sup>s</sup>	−48° 49' 54''	HBL	0.071	22
PKS 2155-304	21 <sup>h</sup> 58 <sup>m</sup> 52.1 <sup>s</sup>	−30° 13' 32''	HBL	0.117	23
BL Lacertae	22 <sup>h</sup> 02 <sup>m</sup> 43.3 <sup>s</sup>	+42° 16' 40''	LBL	0.069	24,25 <sup>c</sup>
1ES 2344+514	23 <sup>h</sup> 47 <sup>m</sup> 04.8 <sup>s</sup>	+51° 42' 18''	HBL	0.044	26
H 2356-309	23 <sup>h</sup> 59 <sup>m</sup> 07.9 <sup>s</sup>	−30° 37' 41''	HBL	0.167	27
<b>Others</b>					
3C 66B	02 <sup>h</sup> 23 <sup>m</sup> 11.4 <sup>s</sup>	+42° 59' 31''	FR1	0.02106	28
M 87	12 <sup>h</sup> 30 <sup>m</sup> 49.4 <sup>s</sup>	+12° 23' 28''	FR1	0.004233	29
Centaurus A	13 <sup>h</sup> 25 <sup>m</sup> 27.6 <sup>s</sup>	−43° 01' 09''	FR1	0.00183	30

<sup>a</sup>See notes for Table 3 for explanation of object types.

<sup>b</sup>The redshift of 3C 66A is considered to be uncertain.

<sup>c</sup>Detection of E>1 TeV emission from 3C 66A and BL Lacertae was first claimed by Neshpor et al. (1998, 2001). The measured fluxes are not consistent with the later measurements made with more sensitive instruments.